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LAYING AND AIMING STUDY FOR ADVANCED LAND COMBAT SYSTEMS PART II

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U.S. ARMY
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New developments in inertial equipment have led to new guidance mechanizations. Computer technology in the past ten years has made outstanding advances in size speed, and lower cost. These advances have brought to the forefront the implementation of strapdown guidance. The purpose of this report is to update a previous study to include strapdown mechanizations.

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I. INTRODUCTION

Since the original study report No. RG-TR-67-18* was published in July 1967, new developments in inertial equipment have led to new guidance mechanizations. When the original report was written, strapdown guidance was a difficult mechanization to implement, principally due to the large and slow computers available at that time. Computer technology in the past 10 years has made outstanding advances in size, speed, and lower cost. These advances have brought to the forefront the implementation of strapdown guidance. The purpose of this report is to update the previous study to include strapdown mechanizations.

II. DESCRIPTION

There are several mechanizations of strapdown systems possible with today's inertial sensor instruments. One can start with a very general classification of conventional systems, tuned systems, and laser or static systems. The conventional system basically uses three single-degree-of freedom integrating gyros in a pulse rebalance mode; the tuned systems use two two-degree-of-freedom tuned rotor gyros, and of course, the laser system uses either three single-axis laser gyros or one crystal ball with the three paths drilled in a solid block of quartz.

Regardless of the type of sensors used, there is no difference in their impact on the laying scheme, since the laying scheme will work equally well for any one of them. Prior to evolving a scheme, there are a few basic limitations to strapped down sensors that the reader should comprehend.

First and foremost, it is very difficult to obtain accurate gyrocompassing information from strapdown systems for the following reasons:

1) It requires highly accurate sensors (at least as accurate as gimballed systems) but these accurate sensors must withstand a much more rugged environment. Precise and rugged devices just don't exist.

2) It requires very accurate and known orientations between the three-gyro input axis. For guidance and navigation, the knowledge of this alignment is not as severe, and the calibration is not performed to the required accuracy for gyrocompassing.

3) Very stable drift performance between calibrations is required more often than with movable gimbal systems.

This does not mean that gyrocompassing cannot be accomplished, but it will take more elaborate techniques than normally associated with

*Johnston, James V., Laying and Aiming Study for Advanced Land Combat Systems, Research and Development Command, Redstone Arsenal, Alabama, July 1967, Technical Report RG-67-18, UNCLASSIFIED.

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gimbal systems. A 90° rotation provides a quick determination of the actual gyro drift in gimbal systems, whereas with strapdown, you either put the system in a 90° gimbal (which defeats the purpose of strapdown) or you rotate the entire vehicle 90°. Also, a strapdown system does not lend itself to a simple backup system for laying, for unlike other Army inertial systems, a visible check does not exist that indicates the direction the missile will fly. Therefore, it is sufficient to say that gyrocompassing is not a highly desirable requirement for strapdown systems.

The following paragraphs will give several schemes and their advantages and disadvantages.

A. Scheme No. 1

Perhaps the first mechanization that should be examined is the system that will be used on SIG-D. In this mechanization the IMU establishes the local vertical through the use of its accelerometers. The arbitrary azimuth of the system is measured from a nominally horizontal missile position. The strapdown navigation computation corrects the dislevelment of the porro prism which is sighted by standard surveying techniques. After the data is entered, the system is commanded to navigate while the launcher is raised to a specific quadrant elevation. Upon reaching this angle, the IMU is commanded back to the align mode until the launch command is given.

1. Advantages

The principal advantage of this mechanization is that simple optical transfer techniques and equipment can be utilized for the laying operation. A rough indication of the intended flight path can be achieved by observing the azimuth angle of the launcher, while still aimed in the general direction of the target, and then comparing with the precomputed target azimuth.

2. Disadvantages

Although the SIG-D launch scheme is a viable method it is by no means the optimum and certainly not the best mechanization for a strapdown IMU. The major disadvantage to this technique is the drift error contributed during the launcher erection. Any operational system utilizing this technique will place an undue burden on requiring low drift performance and highly stable calibration coefficients. This is necessary to keep the azimuth alignment errors, caused by the drift, to a fairly low and acceptable level. The other major disadvantage lies with the launcher operational scheme. When quadrant elevations are used it becomes mandantory that the launcher be aimed in the general direction of the target in order to reduce excess control energy in turning to the desired azimuth. Actual magnitudes of this angle require detailed analysis but ±45° could be considered as a maximum.

Finally, there is the problem of reinitializing the azimuth if there is too long a hold in the firing elevation position. The missile must be lowered and the optical laying repeated. Unfortunately there is no simple and accurate method of supplying an optical reference to the IMU when it is elevated at a QE angle of some 60°. The principal driver of this problem, that requires realignment, is the combination of launcher motion and random drift in the gyros.

3. Operational Impact

As indicated above the principal operational requirement is to include standard surveying equipment for the optical transfer. As a minimum requirement, presurveyed sites of the same survey order and accuracy as the Lance battery are necessary. As outlined in the first study this survey can be supplemented with North Seeking gyros and/or inertial surveying systems that would be indigenous to the firing battalion.

Obviously some erector/launcher costs could be saved by utilizing existing Lance launchers. The shipping and handling containers are an entirely different situation. The Lance is a totally wooden round concept and therefore, it's shipping containers reflect this design requirement. In the case of inertial measuring units it is necessary to check calibration coefficients once every six months to a year. It is not necessary to remove the guidance package from its handling and shipping container to perform a partial check. A check of this nature is done on Pershing guidance units without removing them from their sealed containers. The same technique should be applied to strapdown systems. The only requirements would be an optical window in the shipping container to view the porro prism and inter connect cables from the container housing to the IMU to interrogate the strapdown system. A rectangular shaped box would provide better stability externally and possibly allow greater storage density.

B. Scheme No. 2

One of the principal drawbacks to a manual laying operation is the fact that it is not cost effective, based on the quanity of specially trained surveyors needed to maintain the survey and laying operations. It is desirable to incorporate some form of automatic laying. In order to complete the full requirements of both location and azimuth a land navigator with north alignment available to the required accuracy is necessary. As outlined in the previous report, this land navigator could be part of the launcher vehicle itself, or it could be located in a separate vehicle whereby some form of transfer would take place from vehicle to vehicle. Several forms of mechanical and electro-mechanical transfer systems are available. Transfers of this type are far superior to optical transfers since they do not require careful placement of heavy vehicles in order that optics can be used. When the azimuth information is transferred to the vehicle body or is self contained in the launcher, then some form of mechanical interface between

the IMU and the azimuth reference on the launcher is required. This can be achieved by mechanical machined faces and optical encoders over each moveable axis such as the azimuth and elevation trunnions. In this manner the actual transfer is accomplished through the launcher.

1. Advantages

This system is fully automatic and does not depend on the launcher elevation to initialize the laying. The actual transfer can occur at any time since launcher azimuth and elevation can be ascertained by a simple request from the encoders.

It takes less trained operators and if the navigator is in a separate vehicle it would require fewer expensive navigators since one navigator could roam between several launchers, thereby reducing over-all ground equipment costs.

2. Disadvantages

If the launcher elevates to some fixed QE angle, it is required to be trainable towards the firing azimuth for the reasons discussed previously. Additionally, some fairly elaborate machining alignments must be carried across moveable gimbals and too, accurate launcher angular readouts must be made available.

An accurate, trainable launcher capable of handling possibly two missiles would undoubtedly cost a large percentage of the overall missile system cost. If the capability of full navigation and alignment were also included in the launcher the total cost would be one-half million dollars.

3. New Concepts

One of the features that has not been explored in aiming and laying mechanization is the strapdown system itself. Although strapdown does not lend itself easily to gyrocompassing, it does offer an outstanding advantage in guidance schemes. Some aspects of the guidance mechanization can be exploited to the advantage of the laying and aiming requirements. Simply stated it is, strapdown systems can provide a purely implicit guidance scheme whereby no mechanical aiming of the missile is required nor is there a need for any particular fin to be in the vertical flight plane. The only way to take full advantage of this guidance characteristic is to provide a vertical launch similar to Redstone, Juipter and Pershing.

Of course Redstone, Jupiter and early Pershing systems provided launcher rotation after the missile was erect. With strapdown guidance there is no requirement for launcher rotation. Obviously this characteristic reduces the cost and complexity of the launcher. Unfortunately we cannot gain something for nothing. Bringing the missile totally vertical complicates the aiming problem.

C. Scheme No. 3

The following approach is somewhat similar to the present SIG-D implementation. The basic concept would be to transfer azimuth into the IMU while the missile was in the horizontal position. This transfer could be achieved optically, mechanically or electrically while the missile was located in a precision alignment to the vehicle. When a firing mission order was received the arbitrary azimuth of the strapdown IMU could be determined and the IMU would hold this azimuth as the launcher elevated the missile to the vertical. At this point there would be two alternatives. The first would be a condition where the missile body was removed from its container and attached to the erector holding clamps. When the missile reached the vertical launch position, it would be necessary to set the missile on some form of a base so that the holding clamps could be removed. This would be similar to the Jupiter and Pershing erection system. An alternative to this approach would be to leave the missile in its sealed shipping/ handling container and just clamp the container to the erector. The missile would then be fired directly out of its container which is similar to the Patriot system.

1. Advantage

The advantage on this mechanization is the simplicity of the erector. It does not require any mechanical azimuth rotation, and if the shipping container is used as a launch canister the carrier erector becomes even more simple. If the carrier/erector contains its own inertial navigator, aiming could be coupled directly and mechanically through the canister to the missile frame while it is in the horizontal position-again,somewhat similar to Patriot. In order to keep excessive drift errors to a minimum during erection and the vertical position hold, another feature of the Pershing launch should be incorporated, i.e. the firing command is actually initiated while the missile is horizontal and as soon as the missile becomes vertical, ignition takes place. This sequence requires less than 90 seconds to accomplish.

2. Disadvantage

Here again the prime importance is placed on the gyro drift characteristics. The impact of this error and the requirement for gyro performance are directly proportional to the time required to raise the missile. The only other drawback is the mechanical alignment between the navigator in the vehicle and the strapdown system in the missile.

D. Scheme No. 4

All of the previous techniques required some form of mechanical transfer from the navigator in the carrier to the strapdown system and required fairly good performance gyros to maintain the alignment as the missile was erected. A more direct approach, which would attack

both the gyro performance and the need for a high speed heavy duty erector, would be to erect the missile in the vertical position prior to initialing the laying and firing command. This mechanization simplifies many aspects of the hardware and only complicates the aiming problem. With the missile in the vertical or near vertical position inputting of azimuth information is difficult with any manual techniques. Optical techniques have been used in the past with gimbal platforms simply because the optical reflector is level. It would be very cumbersome to utilize any form of optical transfer of this type for laying. To obtain any speed and accuracy for this operation it mandates the use of a quick electro-mechanical transfer. There are at least two types of mechanical transfer that could be implemented and there are possibly others that could be developed. There is one in particular that offers a lot of merit. This technique can best be described as a transfer head. A transfer head contains a standard two degree-of-freedom gyro and precision synchro resolvers. The head is initially aligned through a mechanical mount to the inertial navigator such as PADS. The precision navigator slaves the gyro to itself and automatically sets biases to trim the drift to levels better than 0.1 degree per hr. The transfer head is unsnapped from the navigator bracket and inserted in a duplicate bracket in the missile. This bracket could be part of the strapdown housing. An immediate electrical read out of azimuth and level would be obtainable at the navigator through the 15-20 foot cable linking the two items.

1. Advantage

With this scheme, minimum requirements of performance are placed on the strapdown components, which obviously puts the lowest cost on the fly away items. Furthermore, if the alignment mount is part of the strapdown IMU housing all other mechanical interface requirements are eliminated thereby reducing cost and improving accuracy. The erector mechanism does not have to be a high speed device since it is no longer a contributor to the laying errors. This simplifies this vehicle and reduces it's cost. Finally, and perhaps the most important, the navigator does not have to be contained in the carrier erector, it could be carried in a jeep utilizing the present configuration of PADS. This brings us to the most interesting possibility of any concept so far. If, after the missile cannister is erected and the jeep is standing by, providing the firing location information, and it was determined that a hold of 30 minutes to a hour would take place, the carrier-erector could leave the area and go back to the supply point for another missile. This arrangement could provide a very high launcher rate capability with minimum investment of ground equipment. This offers a highly attractive approach.

2. Disadvantage

The major drawback to this mechanization is that the missile is standing erect for 30 minutes to an hour. The operational complaint will be one of signature identification. The only way to attack this

problem from the beginning is to make the missile as short as possible and set the rear of the canister as near the ground as possible. The only other disadvantage is that the canister would require some form of stand if the carrier were removed. This could take the form of a re-usable tripod leg that could be pulled out from the canister. This could be a bolt on device after the hold situation was determined. The jeep could possibly retrive the legs after the firing.

III. CONCLUSIONS

There are several variations of any of the above schemes which would be candidates for automatic laying of a strapdown system. The objective of this study report is to present the principal concepts in developing the fastest, lowest cost and most accurate laying scheme available.

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